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Commentary:

Sync or separate? No compelling evidence for unintentional interpersonal coordination between Usain Bolt and Tyson Gay on the 100 m world record race

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Abstract

In a recent observation article in JEP:HPP (Varlet & Richardson, 2015) the 100-m sprint final of the World Championship in Athletics in Berlin of 2009 (i.e., the current world record race) was analyzed. That study reported occurrence of spontaneous, unintentional interpersonal synchronization between Usain Bolt and Tyson Gay, the respective winner and runner-up of that race. In the present commentary paper, however, we argue that the results and conclusion of that study cannot be warranted due to methodological shortcomings. We addressed the same research question and re-assessed the same race using an alternative data analysis method. These results revealed that as yet there is no sufficient ground to conclude that in the 100m world record race synchronization occurred between Bolt and Gay. At the same time, our re-analysis suggested that even at this very elite level the individual movement frequencies did seem to vary to such an extent that synchronization would theoretically not be impossible, thereby providing incentives for further examination of potential unintentional synchronization in co-active sports.

Keywords: interpersonal interaction, entrainment, joint action, social coordination dynamics, between-agent coupling

Public significance statement

While a previous study suggested that in the 100m sprint world record race unintended synchronization occurred between winner Usain Bolt and runner-up Tyson Gay, the present study demonstrates that as yet there is no sufficient ground to conclude this. Still, re-analysis also unveiled that Bolt and Gay varied their step rates to an unexpectedly large degree, given which synchronization would theoretically not be impossible. This further opens up the question when and why athletes in co-active sports would show such variability and potentially synchronization.

Introduction

In competitive sports, athletes interact with each other. In this context, interpersonal coordination is an important concept, whether it concerns coordination between team members, like in rowing (Cuijpers, Zaal & de Poel, 2015), or between opponents, for example in singles tennis (Palut & Zanone, 2005). There is a growing body of literature concerning coordination dynamics within sports. In that realm, a recently published observation study in JEP:HPP (Varlet & Richardson, 2015) reported an analysis of the men's 100-m final of the World Championship in Athletics in 2009. As locomotion entrainment processes have been previously demonstrated in for example side-by-side walking (Nessler & Gilliland, 2009; van Ulzen, Lamoth, Daffertshofer, Semin & Beek, 2008), the authors examined whether - despite the fact that sprinting is a co-active (rather than inter-active) sport discipline - such unintended coordination arose between Usain Bolt and Tyson Gay, the gold and silver medalist of this race. The presented results led the authors to interpret that the two athletes indeed intermittently synchronized their footsteps during the race, which would imply they were unintentionally coupled. As acknowledged by the authors, such a finding would be quite remarkable, given that sprinters should run for themselves (as if 'with blinkers'). Although the issue raised in the article appears valid to examine, in the present paper we will argue that the reliability and accuracy of their presented methods were insufficient for the intended purposes and that, thereby, the associated results and interpretations are not substantiable. Subsequently, we also present results of a reanalysis of the same race, using an alternative analysis method that is to a certain degree more pertinent to address the research question.

To address their research question, Varlet and Richardson (2015) analyzed video footage (30 fps) of the finals. Through frame-by-frame eyeball assessment, two observers separately estimated the occurrence of each step of the two athletes, which was depicted by the frame number where the foot first contacted the ground. Next, the authors calculated the discrete relative phase (*DRP*, in °) between the steps of Bolt (41 steps) and Gay (45 steps). A *DRP* value close to 0° would indicate that Bolt's and Gay's footfalls occurred at the exact same time instant. Next, the distribution of the thus obtained *DRP* values (n=37, as the first 8 steps were not used) was analyzed. For this reason the authors chose to distribute the *DRP* values into nine bins of 40°. The *DRP* time series and according distribution obtained by Varlet and Richardson are shown in Figure 1. Figure 1A shows a drift of the relative phase between Bolt and Gay during the race, which was due to the fact that, given his longer legs, the step frequency of Bolt was lower than that of Gay. Despite this frequency difference, brief instances of phase locking were observed around step 11-14, 24-26, and 35-37. Here, the relative phase temporarily (i.e., for > 1 step) lingered around a value of 0°, which would allegedly indicate that intermittent synchronization had occurred.

Subsequently, to pursue statistical support for the interpretation, each of the nine bins of the DRP distribution was compared to a chance level distribution (see Figure 1B). To do so, the authors generated 100,000 random phase distributions, calculated and sorted the percentages, and subsequently took the 99,000th highest percentage value, which corresponds to a 0.01 significance threshold (i.e., at a value of 24.3%). This analysis revealed that the percentage of *DRP* values in the bin around 0° to be higher than in the other bins and, more importantly, significantly higher than the level of chance.

Together, these results were taken to support that unintended synchronization occurred between the two sprinters. However, in the next section we will argue that these results can not be substantiated, because given the adopted methods the results were vitally prone to measurement errors.

Measurement Error

A crude calculation shows that the temporal resolution of the acquired data was not sufficiently accurate to justify Varlet and Richardson's (2015) methods. Given the sample frequency of the video footage (30 fps) and the time it took Bolt to cover the distance (9.58 s), rounded there were 287 video frames to be assessed. The number of steps that Bolt required to complete the 100 m was 41, so on average there were 7 video frames to cover each step cycle of Bolt (note that for Gay the frame-to-step ratio was even smaller). As each step cycle was defined from 0° to 360°, $1/7^{th}$ of a step cycle thus corresponds to a phase range of 51.4° per frame. Such a margin is too large for sufficiently accurate determination of the exact moment of a footfall: the determined moments of footfall hypothetically reflect a point anywhere between the actual footfall and $1/7^{th}$ of a step cycle before or after that instant. Note also that the inter-step interval could only take a few scalar values, namely 5, 6, 7, or 8 video frames, which correspond to a step frequency of either 6.0, 5.0, 4.29, or 3.75 Hz, respectively. No other values were possible. Thus, for example, this method does not allow for any step frequency values between 4.3 and 5 Hz, which is in reality the main range in which these sprinters would vary their movement frequency. Moreover, the 51.4° phase margin is much larger than the arbitrary phase regions of 40° used for the distribution analysis. Hence, the chosen bin size was smaller than the measurement error; each data point could in principle have been allocated to an adjacent bin. This vital sensitivity to type I error poses problems regarding potential statistical backup. Besides that, Varlet and Richardson's study mentioned that for 9% of the footfall event judgments there were differences between the two observers, which further questions the reliability of the adopted methods and results.

All in all, although the authors posed a very interesting and relevant research question and undoubtedly were conservative in the application of their methods, the temporal resolution of the data was simply too low for their adopted methods (i.e., DRP and distribution analysis based on footfall judgements) to be able to justify the presented results and interpretations. The most obvious way of solving this problem would be to repeat the same analysis based on high-speed (i.e., > 60 fps) video recordings. Finding such footage of this particular race however proved to be less straightforward: although high-speed images of Usain Bolt's start of the race have been broadcasted in Europe, this footage is was not available for the whole race in such a way that footfalls of both Bolt and Gay were visible.

Despite the above, it is possible to examine potential synchronization between Bolt and Gay from the normal footage using another method that allows for higher temporal (i.e., sub-frame) accuracy (see Hamill, Caldwell, & Derrick, 1997). In the remainder of this article we present our alternative analysis of the 100 m final of 2009, in which we examine whether spontaneous motor synchronization between Bolt and Gay may have occurred.

Reanalysis

Method

Full HD video footage (25 fps) of the Dutch national television was acquired. Specifically, we analyzed the footage captured by a side-cam that was moving along with the athletes on a rails parallel to the track.[1] We digitized movement data from each video frame, using Kinovea 0.8.15. Three markers were selected for each athlete in each frame, by manually clicking on the trochanter major and the transverse axis of left and right knee joint (see Figure 2A). Note that the intended markers were indeed not always as clearly determinable in each video frame, for instance due to occlusion in the image by the runner's right arm or leg, or (in case of Tyson Gay) because of Asafa Powel's leg. In such cases we very carefully approximated where the marker would be in the image. Using MATLAB R2014b (The MathWorks Inc.), the digitized pixel coordinates were used to calculate the spatial angle with respect to the vertical for both the right leg (θ_R) and left leg (θ_L) of each athlete. Next, the angle between the left and right leg was determined as $\theta = \theta_R - \theta_L$ (see

Figure 2A). To allow for determination of step cycle events at sub-frame accuracy, we also increased the sample rate ten times using an interpolation method based on Shannon's Sampling Theorem; this procedure is used for reconstruction of digital signals and has been proven to be particularly well-suited for upsampling oscillatory signals, especially for the purposes of determining events at sub-frame level (Hamill, Caldwell, & Derrick, 1997), provided that the original frame rate (in this case 25 Hz) is higher than the Nyquist critical sampling rate. The Nyquist critical rate (f_c) is a critical parameter to subject into the Shannon reconstruction procedure (Hamill et al., 1997): f_c equals two times the highest frequency (f_h) in the signal that is measured (here: the actual between-leg angle). From spectral analysis of the 25 Hz θ-signals, f_h was deemed 2.75 Hz for both Bolt and Gay. Hence, f_c = 5.5 Hz, which is indeed much lower than the original frame rate. This reconstruction procedure yielded interpolated between-leg angle time series (θ_{int}) with a sample rate of 250 Hz. The resulting θ_{int} time series for Bolt and Gay are shown in Figure 2B. Next, we determined the maximal excursions of θ_{int} for both athletes, using a custom made peak-picking algorithm. These peaks are also plotted in Figure 2B. Subsequently, the same method as Varlet and Richardson (2015) was applied to calculate the discrete relative phase:

$$DRP = \frac{t_B - t_G}{T_B} \times 360° \tag{1}$$

where t_B and t_G indicate the time of maximal excursion of Bolt and Gay, respectively, and T_B depicts the time between two successive maximal excursions of Bolt. Similar to Varlet and Richardson, the first eight steps of both athletes were removed from further analysis.

Besides sub-frame approximation of step cycle events, the obtained θ_{int} time series also allowed for estimation of the continuous relative phase (*CRP*) between Bolt and Gay. Although θ_{int} oscillated around a value of 0°, over time there was a slight drift in the center of oscillation. (This drift was primarily due to the fact that in the first few seconds of the race the side-cam was not nicely parallel to the runners yet and footage was thus shot under an angle.[1])

Because such a drift causes artifacts in the calculation of continuous (e.g., Hilbert) phase (Pikovsky, Rosenblum & Kurths, 2001), the center of oscillation was estimated for θ_{int} by using a low-pass Butterworth filter (2nd order, cut-off frequency: 0.1 Hz) on the respective time series. This center of oscillation signal (see Figure 2B) was subtracted from the θ_{int} time series and subsequently the phase angle of each signal was determined using the Hilbert transform (Pikovsky et al., 2001), yielding $\varphi_B(t)$ and $\varphi_G(t)$ for Bolt and Gay, respectively. Thereafter, the continuous relative phase between the athletes was computed as

$$CRP(t) = (\varphi_B(t) - \varphi_G(t)) \times 2 \quad (2)$$

in which the multiplication by a factor 2 was necessary because in the study of Varlet and Richardson (2015; see also Equation 1) a complete movement cycle was defined as a step cycle (left step to right step) rather than a full stride cycle (left step to next left step). The resulting *CRP* signal is displayed in Figure 3B, right panel. Also here, the first eight steps of both athletes were removed from further analysis.

Following Varlet and Richardson (2015), the distributions of the *DRP* and *CRP* measures were obtained by computing the percentage of occurrence across nine 40° phase regions from -180° to 180°, as presented in the histograms (Figure 3, right panels). Furthermore, to statistically compare the distributions to chance level, we generated 100,000 random phase distributions in the same manner as Varlet and Richardson.

Results and discussion

Before we start discussing the results, it is important to realize that our method inevitably differed from that of Varlet and Richardson (2015). As is evident, it was necessary to depart from analyzing eyeball-assessed footfall occurrences because neither from 25 fps nor 30 fps footage this method allows for sufficient accuracy (see above: ‘measurement error’). Therefore we had to find a different variable to examine. Fortunately, based on the side cam footage it was possible to determine the phase relation between Bolt and Gay in another way, namely based on hip flexion-extension angles for each video frame. From these we could approximate moments of extreme hip extension and flexion (which in fact should closely correlate with actual footfall moments) at sub-frame level. To be able to achieve sub-frame accuracy, based on Shannon's Sampling Theorem we reconstructed the data towards a sample rate of 250 Hz. Although all assumptions for applying Shannon's reconstruction were met, it is important to note that the adopted procedure may of course involve some uncertainties, for instance related to potential spatial errors in clicking markers. Nevertheless, our method offers one pertinent alternative for addressing the research question.

Synchronization of two oscillators is understood as adjustment of their rhythms, or appearance of phase locking, due to interaction. In contrast to the results of Varlet and Richardson's (2015) analysis (Figure 1), our analysis revealed no evidence for synchronization between the two sprinters. Figure 3 clearly shows that in neither of the nine phase regions the percentage of occurrence significantly differed from the random phase distribution (note that also none of the percentages significantly differed from chance with a significance threshold of 0.05, corresponding to a value of 18.9%). The *DRP* and *CRP* graphs in the left panels of Figure 3 further underscore this by showing that the relative phase drifted without clearly visible regular occasions of slowdowns or phase locking. If any, around t = 2.40 s, 2.90 s, 3.30 s and 8.60 s of the race, some slowdown might be inferred from the DRP and CRP graphs, though these did not occur at regular instances (i.e., occurred at different phase relations) and also did not last longer than 1 step cycle, which makes it questionable to label these instances as slowdowns due to coupling of oscillators.

Intermittent synchronization would imply that the oscillation frequencies of the two processes briefly align (1:1 frequency locking) or at least become closer at regular instances. The latter implies that Bolt would increase his step frequency and/or Gay decreases his step frequency for at least more than one step cycle. As noted, given his longer legs the step frequency of Bolt is systematically lower than that of Gay. Hence, synchronization would entail the athletes to occasionally deviate from their own preferred (or optimal) step frequency at the given maximal speed (Nessler & Gilliland, 2009), implying they would have to show quite some variation in their step frequency over the course of the race. Because at top speed the range of possible step frequencies is limited, it would however be unlikely that Bolt and Gay (or any top sprinter) briefly changed their step frequency to an extent that is needed to show phase locking. Indeed, a recent study on maximal sprinting performance in world-class sprinters showed that while step length increased regularly during the acceleration phase, step frequency almost instantaneously leveled at the maximal possibility of the athletes (Rabita et al., 2015). Recently published data on the three best 100 m performances ever, including Bolt's 2009 world record race, corroborates this (Krzysztof & Mero, 2013).

When we explored our own data in this context, however, we observed the following. Figure 4 shows the step frequency for both athletes, as calculated from the maximal between-leg excursions (Figure 2B). The difference in mean step frequency of Bolt (4.45 Hz) and Gay (4.87 Hz) during the race was 0.42 Hz. For phase locking to emerge, one or both of the sprinters would thus minimally have had to show epochs where he increased/decreased step frequency by at least 0.21 Hz. Somewhat to our own surprise, inspection of Figure 4 suggests that both Bolt and Gay showed rather large variations in step frequency. These step-to-step changes in step frequency were at some instances even around 0.9 Hz (i.e., approximately 20%) which is remarkably large. Nonetheless, in general the difference between the step frequency of Bolt and Gay was high, while for instance around t = 2.40 s, 2.90 s, 3.30 s and 8.60 s of the race (indeed, logically, the exact same moments at which slowdowns might be inferred) their frequencies became quite close. If any, only at these epochs synchronization (i.e., slowdowns in the phase relation and/or phase locking) between Bolt and Gay may have been possible. Looking at the left panels of Figure 3, we see that at these epochs the relative phase was around -150°, -80°, -20° and 80°, respectively. At the mentioned epochs the step frequencies were close, but not for longer than one step, which cannot be considered as phase locking or slowdowns related to coupling between the two sprinters.

For synchronization to emerge in the current situation, visual and/or auditory coupling between the athletes would be needed. To attain an auditory coupling Bolt and Gay had to be able to hear each other’s steps (or movements). Yet, the stadium was packed with thousands of cheering fans, so the noise of the crowd likely drowned the sound of the running athletes. Regarding visual coupling, during the race Bolt starts to run gradually in front of Gay. Hence, any coupling between the moving athletes would likely be unidirectional or at least highly asymmetric (De Poel, 2016; Meerhoff & De Poel, 2014). So, as also noted by Varlet and Richardson (2015), primarily Gay would be expected to unintentionally adapt his rhythm due to coupling. As synchronization of two oscillators is understood as adjustment of their rhythms due to interaction, entrainment or coupling effects can manifest for instance in individual adaptation in frequency or phase (Meerhoff & De Poel, 2014; Peper, Stins, & De Poel, 2013). To illustrate, from Figure 4 it may be taken that at t = 6.4 - 6.8 s Gay temporarily decreased his step frequency with about 0.2 Hz for three successive steps. As noted, such adjustment of frequency could be interpreted as entrainment effects, though this could also simply reflect individual dynamical process (i.e., movement frequency does not only vary due to coupling), as both Bolt and Gay appear to demonstrate variations in individual step frequency that are much larger than 0.2 Hz.

Conclusion

The current study argues that there is no clear sign of perceptual coupling effects between Bolt and Gay. While we showed that the study of Varlet and Richardson (2015) was subject to methodological shortcomings, our re-analysis using methods that allowed for higher temporal (sub-frame) accuracy did not yield sufficient grounds to conclude that Bolt and Gay synchronized. Still, the surprisingly large variation in individual movement frequencies that we observed suggested that, also at this very elite level of sprinting, movement frequencies are in fact adaptable to such an extent that synchronization would theoretically not be impossible. Although such variations might call for interpretation in terms of coupling and entrainment, caution is at hand and it first needs to be evaluated alongside for instance typical individual variations in movement frequency.

In the current paper we offered one possibility for re-analyzing the world record race, but a closer examination of the current research question would be warranted. The latter would vitally require high-speed footage of this race, which is unfortunately difficult (if not impossible) to achieve. Notwithstanding, the study of unintended synchronization (and movement variability in general) could likely benefit from generalization to other 100m races and -sprinters, and perhaps other track & field disciplines, and even to other co-active sports. As such, the present study offers entry points towards the challenging endeavor to further examine potential presence of unintentional synchronization in co-active sports.

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Footnote

[1]For an indication of the side-cam footage - starting at 5 min 48 s - see the following link: http://www.youtube.com/watch?v=I1YnES6jUa8. Note that 1) the actual video data that we acquired and analyzed were of much higher quality (HD), and 2) it appeared that these side-cam images of the whole race were not broadcasted in the US, hence we were not able to acquire these recording in 30 fps.

Figure 1. Graphic representation of the results adapted from Varlet & Richardson (2015). A) Discrete relative phase as a function of time. B) Histogram with the percentage of occurrence for the nine relative phase regions. Blue (dark) bars: discrete relative phase (DRP), yellow (grey) bars: average of the control random distribution (CR). The dotted line represents the 0.01 significance threshold. See the online article for the color version of this figure.

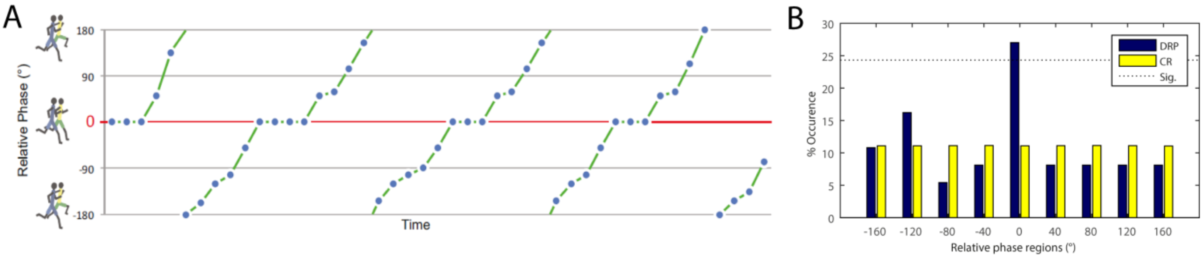

Figure 2. Between-leg spatial angles. A) Schematic illustration of three video frames indicating the placement of markers for digitization of pixel coordinates (trochanter major and the transverse axis of each knee joint) and determination of angle between the upper legs (θ_G and θ_B). B) Angle between right and left upper leg for Usain Bolt ($\theta_{B\text{-}int}$, upper panel) and Tyson Gay ($\theta_{G\text{-}int}$, lower panel) as a function of time. A negative value indicates the left leg is in front of the right leg. The '×' and '✯' symbols indicate the maximal excursions; Horizontal doted curve indicates center of oscillation signal; Vertical dotted line at 2.15 s shows the eighth step of Usain Bolt. See the online article for the color version of this figure. (Note that these illustrations represent the actual video frames. Signed permission for printing the actual video frames in the journal could unfortunately not be achieved; for examples of the actual video frames see Footnote 1)

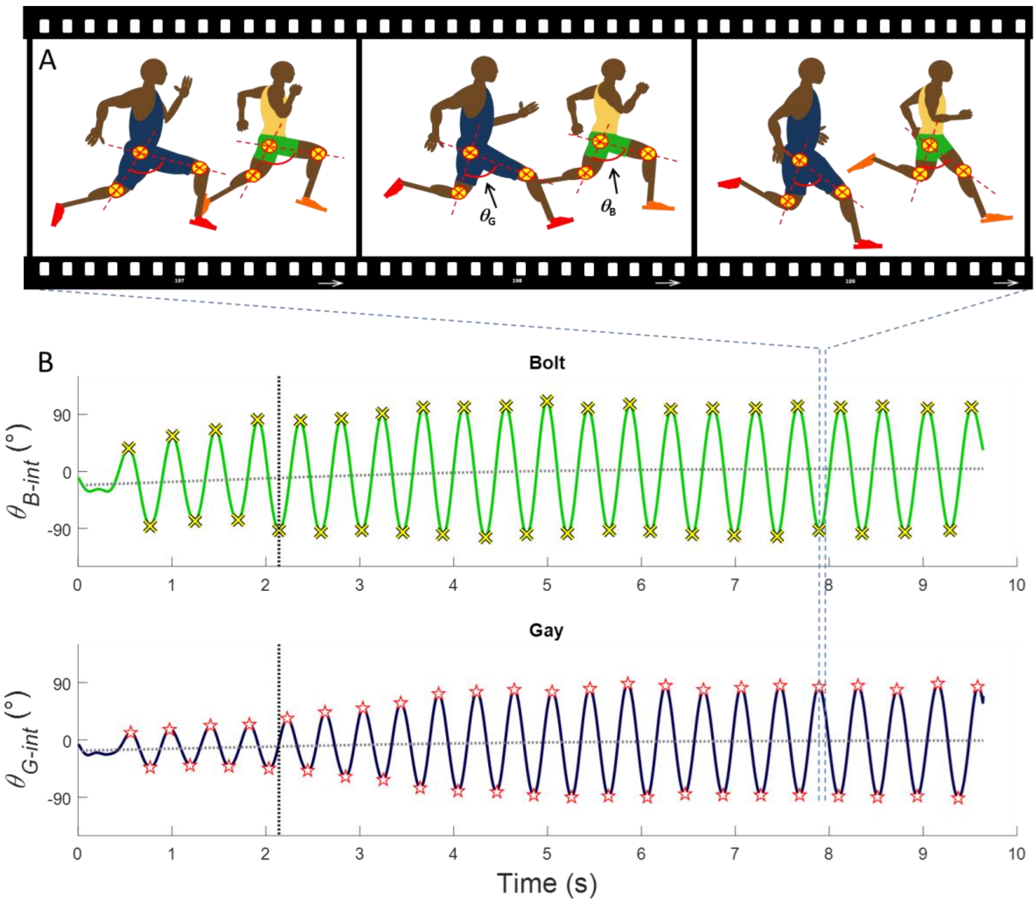

Figure 3. Relative phase and distributions thereof. Left columns: relative phase between Usain Bolt and Tyson Gay as a function of time based on A) discrete relative phase (*DRP*), B) continuous relative phase (*CRP*). The vertical dotted line indicates the eighth step of Usain Bolt. Right columns show the according histograms with the percentage of occurrence for the nine relative phase regions. Blue (dark) bars depict the analyzed relative phase data, and the yellow (grey) bars display the average of the control random (CR). The dotted line represents the 0.01 significance threshold. See the online article for the color version of this figure.

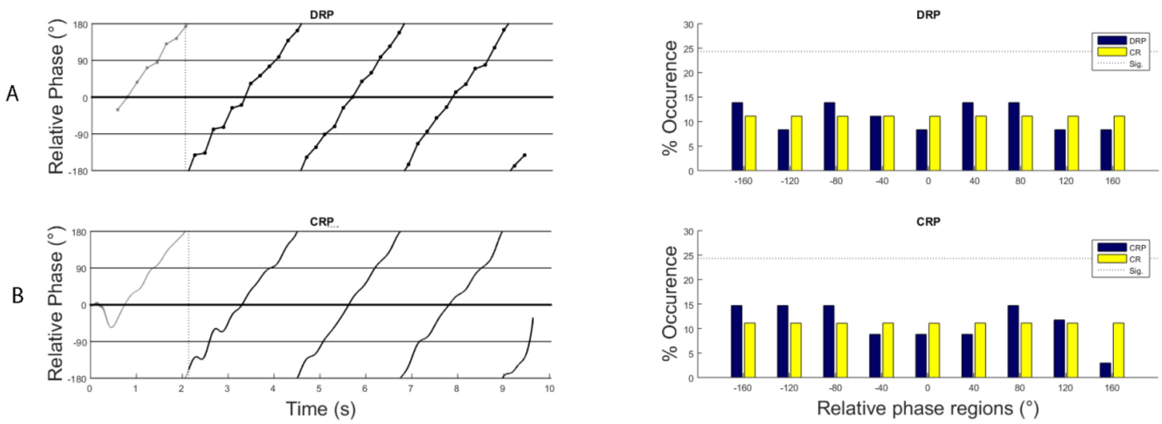

Figure 4. Individual step frequencies of Bolt and Gay as a function of time. The '×' and '✭' symbols indicate the maximal excursions. See the online article for the color version of this figure.